V. Toporov, D.Dobrunov

OIL AND GAS PRODUCTION TECHNOLOGY

Practical training manual

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This training manual is recommended to publish by scientific society of the department "Organic substances technology" in National Technical University "Kharkov Polytechnic Institute"

This training manual includes practical works on the course "**Oil and gas production technology**" in English.

The **petroleum industry** include the global processes of exploration, extraction, refining, transporting (often by oil tankers and pipelines), and marketing petroleum products. The largest volume products of the industry are fuel oil, gasoline (petrol) and natural gas. The industry is usually divided into three major components: upstream, midstream and downstream.

Upstream sector of petroleum industry includes exploration, development and production of crude oil or natural gas.

Practical works acquaint students with the calculation methods of some processes and equipment used in the oil-gas production.

The manual is intended for the students trained on a speciality 6.050304 "Oil and gas extraction" in English.

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CONTENT

PRACTICAL WORK GENERAL GUIDANCE

1. By means of lectures or textbooks a corresponding theme of oil-gas production must be studied before performing the practical work.
2. To choose option number of the initial data and make the necessary calculations.
3. To perform analysis of obtained results.
4. Practical work executive summary (report) should include:
   a) title page, designed in accordance with Appendix 1, in which must be specified:
      - the name of the object being studied;
      - the group number of the student;
      - full name of the student, who performed the project;
      - option number of the practical work initial data;
      - full name of the teacher, who check the practical work.

   b) theoretical part of the practical work (**to be rewritten!**)

   c) the initial data selected in accordance with option number;

   d) performed calculations (graphics, nomograms, etc.)
5. Practical work can be considered as completed one, if it is checked and approved by the teacher.

Practical work № 1-Pr
Properties of oil at reservoir conditions

1.1 Theoretical part

Gas factor of reservoir *oil (Gf)* show the ratio of the released gas volume (Vg) to the volume of degassed oil, which is obtained from reservoir oil in the process of its degassing (Vo):

$$Gf = \frac{V_g}{V_o} \tag{1.1}$$

Volume of the evolved gas (Vg) must be cast to standard conditions (atmospheric pressure - 100 kPa, temperature – 293.15 K) or to normal conditions (0.1013 MPa, 273.15 K).

Saturation pressure of the reservoir oil is called the maximum pressure at which the dissolved gas begins to flow from the oil during its isothermal expansion under thermodynamic equilibrium. In reservoir conditions before deposits developing saturation pressure may be equal to the reservoir pressure (oil is fully saturated with gas) or be less than the reservoir pressure (oil is not fully saturated with gas), but cannot be greater than the reservoir pressure.

Oil and formation water with a saturation pressure equal to the reservoir pressure, are called saturated. If the reservoir has a gas cap, the oil usually is fully saturated.

The difference between $\mathbf{P_{str}}$ and $\mathbf{P_{sat}}$ can range from tenth parts to tens MPa. Samples of oil selected from the same reservoir, have different indicators on the pressure value of saturation. This is due to the change of oil and gas composition and properties within the reservoir. Saturation pressure depends on reservoir temperature, the volume ratio of oil and dissolved gas, their composition and properties. With increasing temperature, the saturation pressure may increase significantly.

Oil formation volume factor

With the amount of the dissolved in oil gas is also associated **volume factor *b***, which characterizes ratio of the oil volume in reservoir conditions and the oil volume after separation of the gas on the surface during degassing:

$$b = \frac{V_{STR}}{V_{DEG}}, \tag{1.2}$$

where Vstr - the oil volume in reservoir conditions;

Vdeg - the oil volume at atmospheric pressure and a temperature of 20° C after degassing.

The oil volume at reservoir conditions is always greater than the volume of the separated oil (Vstr> Vdeg). By using the volumetric ratio can be determined **shrinkage of oil** (U), that is volume reduction of reservoir oil after extraction it onto the surface (%):

$$U = \frac{b-1}{b} \cdot 100\% \qquad (1.3)$$

1.2. A typical task

Is known: According to the results of the well test operation at new oil field are obtained the following data:

1. Reservoir pressure ***Pstr*** = 180 atm;
2. Reservoir temperature ***tstr*** = 60 °C;
3. Oil density at standard conditions ρ_{oil} = 850 kg/m^3 = 0.85 t/m^3;
4. Relative density of the gas (by air) for normal conditions Δ_0 = 0.9;
5. Gas factor ***Gf*** = 128 m^3/m^3, all gas is dissolved in the oil.

Determine the properties of oil at reservoir conditions:

- saturation pressure (***Psat***),
- oil formation volume factor ***(b)***,
- density of oil at reservoir conditions ($\rho_{Oil.STR}$),
- oil shrinkage factor (***U***).

Solution:

1. To assess Psat is used M. Standing's nomogram 1 (Fig. 1.1):

Gf = 128 m^3/m^3 → **Psat** = 175 atm.

Thus, the sequence of actions at work with the diagram №1 – is as follows:

1. gas factor– horizontal line to the gas relative density;
2. vertical line down to the intersection with line of oil density;
3. horizontal line to the line of reservoir temperature;
4. vertical line down to the oil saturation pressure by gas.

2. For determination of oil formation volume factor (b) is used M. Standing's nomogram 2 (Fig. 1.2):

Gf = 128 m^3/m^3 → **b** = 1.23.

Thus, the sequence of actions at work with the diagram №2 – is as follows:

1. gas factor– horizontal line to the gas relative density;
2. vertical line down to the intersection with line of oil density;
3. horizontal line to the line of reservoir temperature;
4. vertical line down to the reservoir pressure;
5. horizontal line to the value of the **volume ratio of oil.**

3. Determination of oil density at reservoir conditions ($\rho_{STR.O}$).

3.1. We find weight of the gas which is dissolved in 1 m^3 of oil ($G_{STR.G}$):

$$G_{STR.G} = \rho_{Oil} \cdot Gfo \cdot G_{Air} \cdot \Delta_0 ,$$

where ρ_O = 0.85 t/m^3 – oil density;

Gfo - weight gas factor $Gfo = Gf / \rho_{Oil},$

$\boldsymbol{G_{Air}} \approx 1.293$ kg, – weight of 1 m^3 of air at normal conditions;
$\boldsymbol{\Delta_0} = 0.9$ – relative density of the gas by air.

$$\boldsymbol{Gfo = Gf / \rho_{Oil} = 128 / 850 = 0.151\ m^3/kg}$$

$$G_{STR.G} = 850 \bullet 0.151 \bullet 1.293 \bullet 0.9 \approx 149 \text{ kg.}$$

3.2. The total weight of the saturated with gas oil at normal conditions (**G_{OilG}**) is:

$$\boldsymbol{G_{OilG} = G_{Oil} + G_{STR.G}}$$

$$\boldsymbol{G_{Oil} = \rho oil \cdot 1\ m^3 = 850\ kg}$$

$$G_{OilG} = 850 + 149 = 999 \text{ kg.}$$

3.3. When we know the oil formation volume factor, we can calculate the density of the oil at reservoir conditions $\rho_{Oil.STR}$:

$$\boldsymbol{\rho_{Oil.STR} = G_{OilG} / b}$$

$$\rho_{Oil.STR} = 999 / 1.23 = 812.2 \text{ kg/m}^3$$

4. Determination of oil shrinkage factor (U).

Oil shrinkage is due to release out from oil dissolved gas (degassing)

$$U = \frac{b-1}{b}$$

$$U = (1.23 - 1) / 1.23 = 0.187 \text{ or } 18.7\%.$$

1.3. Tasks for independent work

You have to define the properties of oil at reservoir conditions:

- saturation pressure (***Psat***) using ***nomogram 1 (Fig. 1.1)***;
- oil formation volume factor ***(b)*** using ***nomogram 2 (Fig. 1.2)***;
  Nomograms should be copied and shown on them the order of calculations.
- density of oil at reservoir conditions ***($\rho_{Oil.STR}$)***;
- oil shrinkage factor (***U***).

Input data are presented in Table 1.1.

B – 1, ..., 30 - the variant numbers for the **group “B”**,
B – 31, ..., 60 - the variant numbers for the **group “G”.**

Pstr **=** _____ atm;
tstr **=** ______ ° C;
ρoil = _______kg/m³;
Δ_0 = ______;
Gf **=** _______ m³/m³.

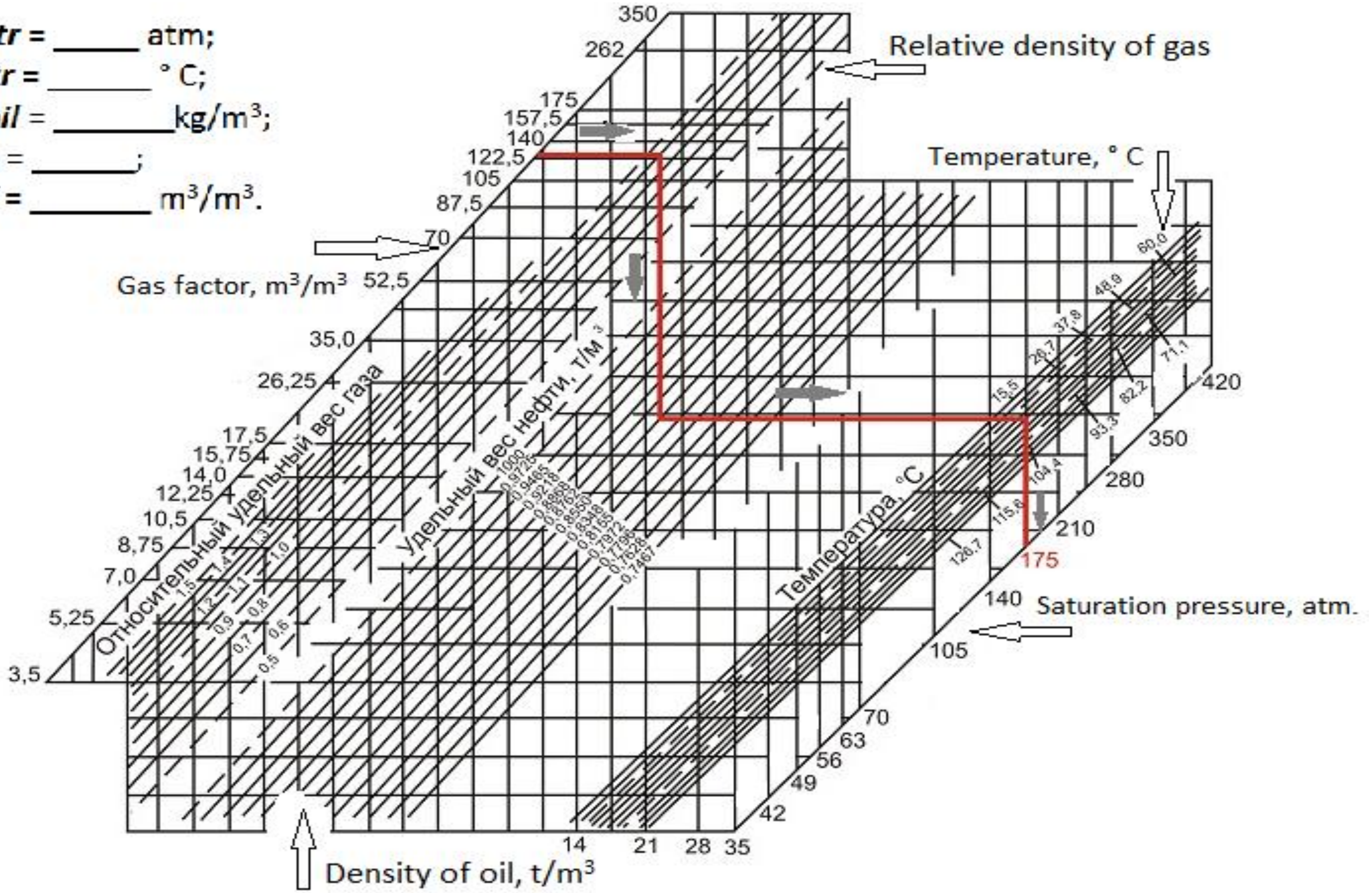

Fig. 1.1. M. Standing's nomogram 1 for determining the saturation pressure

Pstr = ______ atm;

tstr = _______ ° C;

ρoil = ________kg/m^3;

Δ_0 = _______;

Gf = ________ m^3/m^3.

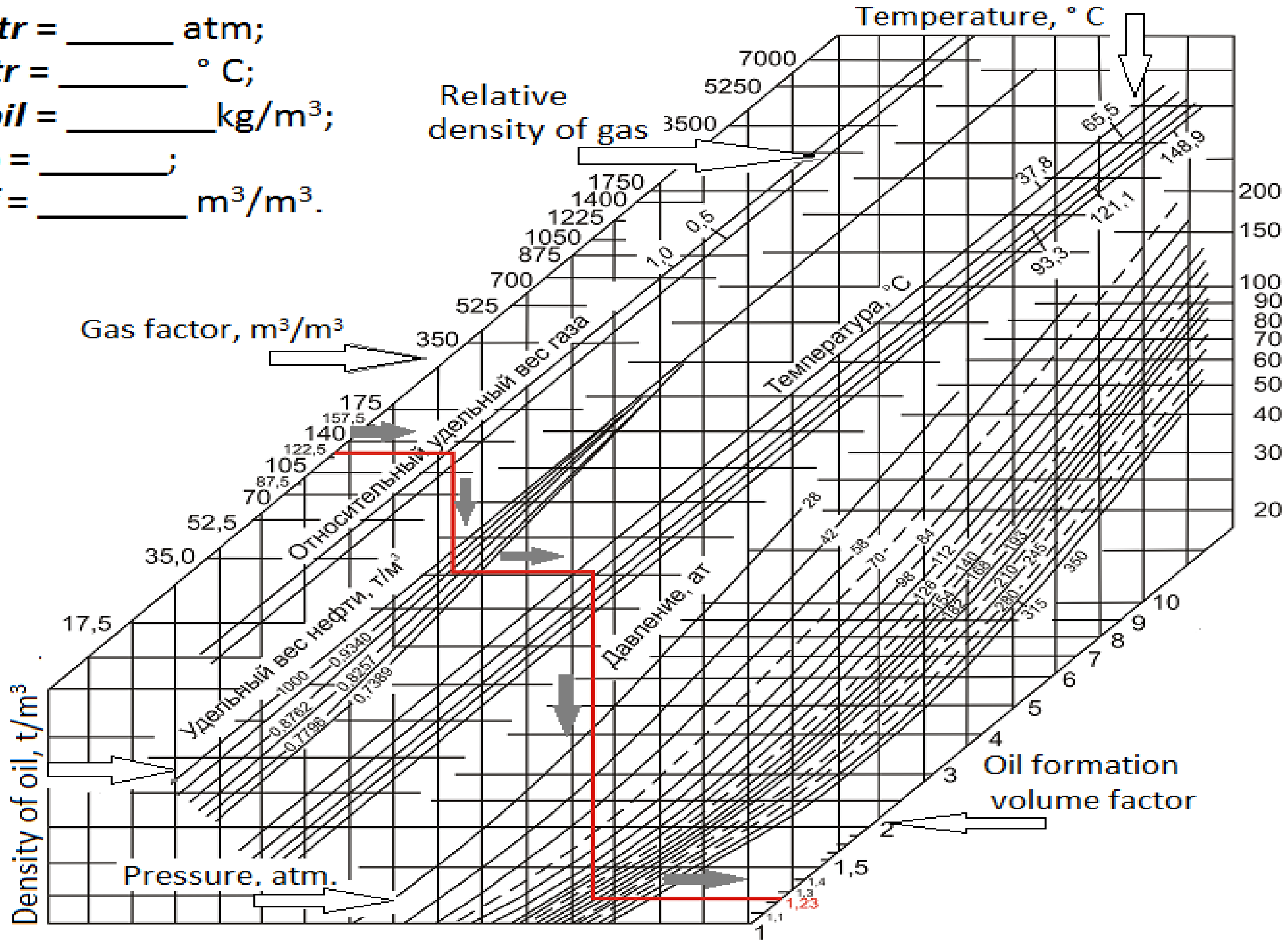

Fig. 1.2. M. Standing's nomogram 2 for determining the oil formation volume factor under reservoir conditions

1.4 Initial data

Legend:

- ***Pstr*** - reservoir pressure, atm;
- ***tstr*** - reservoir temperature, ° C;
- ***ρoil*** - oil density at normal conditions, kg/m^3;
- ***Δ_0***- relative density of gas (by air) for normal conditions;
- ***Gf*** - gas factor, m^3/m^3.

Таблица 1.1

B	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Pstr	240	250	260	280	320	240	250	260	280	280
tstr	70	75	80	85	60	85	90	75	80	90
ρoil	850	840	850	830	840	860	870	840	850	870
Δ_0	0.7	0.8	0.85	0.9	0.8	0.8	0.9	0.7	0.75	0.8
Gf	100	110	140	150	160	90	110	105	130	140
B	***11***	***12***	***13***	***14***	***15***	***16***	***17***	***18***	***19***	***20***
Pstr	280	320	310	310	290	290	300	310	260	240
tstr	95	100	90	70	90	95	85	100	75	65
ρoil	830	820	830	840	880	890	870	860	850	860
Δ_0	0.9	0.85	0.8	0.7	0.9	0.85	0.7	0.8	0.9	0.8
Gf	105	150	110	140	100	140	110	140	90	110
B	***21***	***22***	***23***	***24***	***25***	***26***	***27***	***28***	***29***	***30***
Pstr	300	290	310	270	290	290	280	270	290	280
tstr	80	85	90	95	100	70	65	95	90	100
ρoil	850	830	840	870	890	860	830	870	880	890
Δ_0	0.7	0.65	0.7	0.8	0.9	0.8	0.85	0.9	0.7	0.8
Gf	90	140	150	110	160	90	175	140	150	110
B	***31***	***32***	***33***	***34***	***35***	***36***	***37***	***38***	***39***	***40***
Pstr	275	270	300	290	330	280	310	320	300	310
tstr	80	85	75	80	70	90	95	85	80	60
ρoil	840	850	840	870	890	880	870	860	850	870
Δ_0	0.9	0.7	0.8	0.7	0.9	0.75	0.8	0.9	0.6	0.7
Gf	160	150	105	150	160	105	150	90	160	150
B	***41***	***42***	***43***	***44***	***45***	***46***	***47***	***48***	***49***	***50***
Pstr	300	290	320	320	300	310	260	240	300	290
tstr	100	70	90	95	85	100	75	65	80	85
ρoil	860	840	880	890	840	850	840	870	890	880
Δ_0	0.8	0.9	0.7	0.8	0.9	0.7	0.8	0.7	0.9	0.75
Gf	175	140	90	150	100	140	80	100	90	140
B	***51***	***52***	***53***	***54***	***55***	***56***	***57***	***58***	***59***	***60***
Pstr	310	270	290	290	280	270	240	250	260	280
tstr	90	95	100	70	65	95	90	100	80	85
ρoil	870	860	850	870	860	840	880	890	870	860
Δ_0	0.8	0.9	0.6	0.7	0.8	0.9	0.7	0.8	0.85	0.9
Gf	150	100	90	80	100	140	90	160	140	150

Practical work 2-Pr

Calculations outflow of liquids through the bean

2.1 Theoretical part

Choke (choke valve) – is a type of control valves, mostly used in oil and gas production wells to control the flow of well fluids being produced. Another purpose that the choke serves is to limit the pressure from reservoir and to regulate the downstream pressure in the flowlines.

Bean – is well flow rate limiter with a fixed flow area (constant diameter of the hole). In fact the bean is non-regulating choke.

Hence with dropping reservoir pressure, the non-regulating valves may have to be changed to maintain the same well production levels.

Volumetric flow rate of liquids through the holes and beans (bean length is usually three to four diameters of the hole) in the atmosphere or in space filled with the same fluid is described by general formula Torricelli:

$$Q_{Ps} = \mu_{bn} \cdot \omega_{bn} \sqrt{\frac{2 \cdot \Delta P_{bn}}{\rho}} \tag{2.1}$$

where Q_{Ps} – volumetric flow rate (per second), m^3/s;

μ_{bn}-hole dimensionless flow coefficient of the hole or bean (μ_{bn} <1):

$$\mu_{bn} = \varepsilon_{st} \cdot \varphi_{bn};$$

ε_{st} – dimensionless compression ratio of stream;

φ_{bn} – dimensionless rate coefficient of liquids leakage;

ω_{bn} – cross sectional area of the hole or bean, m^2;

ΔP_{bn} – pressure drop in the hole or bean (nozzle, choke), Pa;

ρ – density of the liquid, kg/m^3.

Coefficient of the hole or bean μ_{bn} depends on the Reynolds, Froude and Weber numbers. Below in the Table 2.1 are values of coefficients ε_{st} *and·* φ_{bn} for different beans.

Table 2.1 – Coefficients ε_{st} *and·* φ_{bn} for the different beans

№	Type of bean ‘	$\boldsymbol{\varepsilon_{st}}$	$\boldsymbol{\varphi_{bn}}$
1	A round hole	0.64	0.97
2	The outer cylindrical bean	1.0	0.82
3	The inner cylindrical bean	1.0	0.707
4	The conical bean (nozzle)	1.0	0.98
5	The conical bean with divergent angle of 5-7 °	1.0	0.475
6	The conical bean with convergent angle of 13°24’	0.98	0.96

From equation (2.1) can determine the diameter of the hole or bean:

$$d_{bn} = \sqrt{\frac{4 \cdot Q_{Ps}}{\pi \cdot \mu_{bn} \cdot \sqrt{\frac{2 \cdot \Delta P_{bn}}{\rho}}}} \quad (2.2)$$

or pressure drop in the hole or bean:

$$\Delta P_{bn} = \frac{{Q_{Ps}}^2}{2 \cdot \mu_{bn}^2 \cdot \omega_{bn}^2} \quad (2.3)$$

2.2 A typical tasks

Calculate the diameter of the bean for flowing well operation.

Obtained the following data:

1. volumetric flow rate of product Q_P = 5.256 m^3/h;
2. density of oil is ρ_O= 865 kg/m^3;
3. density of water is ρ_W =1015 kg/m^3;
4. water content ratio of product n_W= 0.4;
5. type of bean is a round hole (N = 1);
6. pressure drop in the hole or bean ΔP_{bn} = 2 MPa.

Solution:

We calculate:

- volumetric flow rate of product per second:

$Q_{Ps} = Q_P / 3600$ = 5.256 / 3600 = 0.00146 m^3/s;

- density of liquid:

$\rho = \rho_O \cdot (1 - n_W) + \rho_W \cdot n_W$ = 865·(1 – 0.4)+1015 · 0.4 = 925 kg/m^3;

- hole dimensionless flow coefficient for round hole (N = 1):

$\mu_{0T} = \varepsilon_{cm} \cdot \varphi_{bn}$ = 0.64 · 0.97 = 0.62;

where ε_{st} – dimensionless compression ratio of stream (Table 2.1);

φ_{bn} – dimensionless rate coefficient of liquids leakage;

- diameter of the hole or bean:

$$d_{bn} = \sqrt{\frac{4 \cdot Q_{Ps}}{\pi \cdot \mu_{bn} \cdot \sqrt{\frac{2 \cdot \Delta P_{bn}}{\rho}}}} = \sqrt{\frac{4 \cdot 0{,}00146}{3{,}14 \cdot 0{,}62 \cdot \sqrt{\frac{2 \cdot 2 \cdot 10^6}{925}}}} =$$

=0.0067 m = 6.7 mm.

***Answer:* d_{bn} =** 6.7 mm.

2.3 Task for independent work

You must calculate the diameter of the bean for flowing well operation. Input data are presented in Table 2.2.

B – 1. .... 30 - the option numbers for **group "B"**;

B – 31. .... 60 - the option numbers for **group "G".**

2.4 Initial data

Legend:

- Q_P – volumetric flow rate of product. m^3/h;
- ρ_O – density of oil. kg/m^3;
- ρ_W –density of water. kg/m^3;
- n_W – water content ratio of product % ;
- N – type of bean

ΔP_{bn} = 1.5 MPa – pressure drop in the hole or bean (**for all variants**).

Table 2.2

B	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Q_P	240	250	260	280	320	240	250	260	280	280
ρ_W	1070	1025	1010	1015	1060	1035	1105	1015	1020	1030
ρ_O	850	840	850	830	840	860	870	840	850	870
n_W	20	10	40	50	60	30	10	20	30	40
N	1	2	3	4	5	6	1	2	3	4
B	***11***	***12***	***13***	***14***	***15***	***16***	***17***	***18***	***19***	***20***
Q_P	280	320	310	310	290	290	300	310	260	240
ρ_W	1070	1025	1010	1015	1060	1035	1105	1015	1020	1030
ρ_O	830	820	830	840	880	890	870	860	850	860
n_W	10	50	10	40	30	40	10	40	30	10
N	5	6	1	2	3	4	5	6	1	2
B	***21***	***22***	***23***	***24***	***25***	***26***	***27***	***28***	***29***	***30***
Q_P	300	290	310	270	290	290	280	270	290	280
ρ_W	1110	1025	1020	1015	1060	1035	1115	1015	1025	1030
ρ_O	850	830	840	870	890	860	830	870	880	890
n_W	20	40	50	15	30	30	15	40	50	20
N	3	4	5	6	1	2	3	4	5	6
B	***31***	***32***	***33***	***34***	***35***	***36***	***37***	***38***	***39***	***40***
Q_P	275	270	300	290	330	280	310	320	300	310
ρ_W	1110	1025	1020	1015	1060	1035	1015	1015	1025	1030
ρ_O	840	850	840	870	890	880	870	860	850	870
n_W	20	10	40	50	60	30	10	20	30	40
N	1	2	3	4	5	6	1	2	3	4
B	***41***	***42***	***43***	***44***	***45***	***46***	***47***	***48***	***49***	***50***
Q_P	300	290	320	320	300	310	260	240	300	290
ρ_W	1070	1025	1110	1015	1060	1035	1105	1015	1020	1030
ρ_O	860	840	880	890	840	850	840	870	890	880
n_W	20	40	50	15	30	30	15	40	50	20
N	5	6	1	2	3	4	5	6	1	2
B	***51***	***52***	***53***	***54***	***55***	***56***	***57***	***58***	***59***	***60***
Q_P	310	270	290	290	280	270	240	250	260	280
ρ_W	1040	1025	1015	1115	1060	1035	1045	1015	1020	1030
ρ_O	870	860	850	870	860	840	880	890	870	860
n_W	15	50	25	40	30	40	10	40	30	10
N	3	4	5	6	1	2	3	4	5	6

Practical work № 3-Pr
Calculations gas outflow through the bean

3.1 Theoretical part

Bean – is well flow rate limiter with a fixed flow area (constant diameter of the hole). In fact the bean is non-regulating choke.

Volumetric flow rate of gas in adiabatic movement (no heat exchange with the environment) through the hole or bean (nozzle, choke) is described with modified Saint-Wenan-Vantsel' formula:

$$Q_G = \mu_{bn} \cdot \omega_{bn} \cdot \sqrt{2 \cdot R} \cdot \frac{p_1 \cdot T_0}{p_0} \cdot \sqrt{\frac{1}{T_1 \cdot M_G} \cdot \frac{k}{k-1} \cdot \left[\left(\frac{p_2}{p_1}\right)^{2/k} - \left(\frac{p_2}{p_1}\right)^{(k+1)/k}\right]} \qquad (3.1)$$

where Q_G – volumetric gas flow rate under standard conditions (p_0 = 0.1 MPa; T_0 = 273K), m^3/s;

p_1, T_1 – temperature and pressure at the bean (choke) inlet, Pa and K;

p_2 – pressure after the bean (choke), Pa;

μ_{bn} –dimensionless flow coefficient of the hole or bean (μ_{bn} <1). For nozzle with lemniscate profile (μ_{bn} = 0.95-0.98, for conical nozzles with different cone angles μ_{bn} value may decrease up to 0.65);

k – adiabatic index (it depends weakly on changes in temperature and molecular weight of hydrocarbon gas, so in practice with sufficient accuracy can be taken as k = 1.25-1.30);

R – universal gas constant, R = 8314.3 J/(kmol · K);

M_G – molar mass of gas, kg/kmol;

Indexes 1 and 2 refer to the gas parameters before and after the bean (choke) respectively.

Using of this formula is limited with the critical pressure ratio:

$$\left(\frac{p_2}{p_1}\right)_{CR} = \left(\frac{2}{k+1}\right)^{k/(k-1)}, \qquad (3.2)$$

With this ratio the flow velocity reaches the speed of sound, and the gas flow becomes the maximum. That is this formula is valid for $p_2/p_1 > (p_2/p_1)_{CR}$.

If $p_2/p_1 \le (p_2/p_1)_{CR}$. the maximum gas flow is equal to:

$$Q_G = \mu_{bn} \cdot \omega_{bn} \cdot \sqrt{R} \cdot \frac{p_1 \cdot T_0}{p_0} \cdot \sqrt{\frac{1}{T_1 \cdot M_G} \cdot k \cdot \left(\frac{2}{k+1}\right)^{(k+1)/(k-1)}} \qquad (3.3)$$

To determine the diameter of the nozzle or bean (m), these formulas are written as:

1. If $p_2/p_1 > (p_2/p_1)_{CR}$. (formula A):

$$d_{bn}=\sqrt{\frac{4\cdot Q_G\cdot p_0}{\pi\cdot\mu_{bn}\cdot p_1\cdot T_0\cdot\sqrt{2\cdot R}\cdot\sqrt{\frac{1}{T_1\cdot M_G}\cdot\frac{k}{k-1}\cdot\left[\left(\frac{p_2}{p_1}\right)^{2/k}-\left(\frac{p_2}{p_1}\right)^{(k+1)/k}\right]}}}\qquad\text{(A-3.4)}$$

2. If $p_2/p_1 \le (p_2/p_1)_{CR}$ (formula B):

$$d_{bn}=\sqrt{\frac{4\cdot Q_G\cdot p_0}{\pi\cdot\mu_{bn}\cdot p_1\cdot T_0\cdot\sqrt{R}\cdot\sqrt{\frac{1}{T_1\cdot M_G}\cdot k\cdot\left(\frac{2}{k+1}\right)^{(k+1)/(k-1)}}}}\qquad\text{(B-3.5)}$$

According to the last formula (3.5) is defined nozzle or bean diameter in which is provided a critical outflow of gas with a given flow rate Q_G. Pressure at the critical outflow p_2 is equal:

$$p_2=p_1\cdot\left(\frac{p_2}{p_1}\right)_{CR}=p_1\cdot\left(\frac{2}{k+1}\right)^{k/(k-1)}\qquad(3.6)$$

3.2 A typical tasks

Task 1. Calculate the bean diameter on the gas line.

Is known: the pressures at the inlet and outlet of the bean are 8.0 MPa and 5.1 MPa respectively, gas flow rate is equal 160 thousand m^3/day; inlet gas temperature is 288 K, the gas molar mass is 30.2 kg/kmol, adiabatic index k = 1.25;

Solution. Checking the condition of gas outflow:

$$\left(\frac{p_2}{p_1}\right)_{CR}=\left(\frac{2}{1{,}25+1}\right)^{1{,}25/(1{,}25-1)}=0{,}555$$

$$\left(\frac{p_2}{p_1}\right)=\frac{5{,}1}{8{,}0}=0{,}638.$$

As $p_2/p_1 > (p_2/p_1)_{CR}$, a bean diameter is calculated by the formula (A-3.4).

Volumetric flow rate of product per second is equal:

$Q_{Gs} = Q_G/86400 = 160\cdot10^3/86400 = 1.8519$ m^3/s.

$$d_{bn}=\sqrt{\frac{4\cdot1{,}8519\cdot10^5}{3{,}14\cdot0{,}96\cdot8\cdot10^6\cdot293\cdot\sqrt{2\cdot8314{,}3}\cdot\sqrt{\frac{1}{288\cdot30{,}2}\cdot\frac{1{,}25}{1{,}25-1}\cdot\left[(0{,}638)^{2/1{,}25}-(0{,}638)^{(1{,}25+1)/1{,}25}\right]}}}=$$

$=12.9\cdot10^{-3}$ m = 12.9 mm.

Task 2. According to data **Task 1** is necessary to calculate the bean diameter and the pressure at outlet of the bean when inlet pressure is equal to 8 MPa, but there is a critical gas outflow with a constant flow rate 160 thousand m^3/day.

Solution. We calculate the diameter of bean according with formula (B-3.5):

$$d_{bn} = \sqrt{\frac{4 \cdot 1{,}8519 \cdot 10^5}{3{,}14 \cdot 0{,}96 \cdot 8 \cdot 10^6 \cdot 293 \cdot \sqrt{8314{,}3} \cdot \sqrt{\frac{1}{288 \cdot 30{,}2} \cdot 1{,}25 \cdot \left(\frac{2}{1{,}25+1}\right)^{(1{,}25+1)/(1{,}25-1)}}}} =$$

$=12.76 \cdot 10^{-3}$ m = 12.8 mm.

The pressure at the outlet is (formula 3.6):

$$p_2 = 8 \cdot 10^6 \cdot \left(\frac{2}{1{,}25+1}\right)^{1{,}25/(1{,}25-1)} = 4{,}44 \cdot 10^6 \text{ Pa}$$

Answer: 12.8 mm; 4.44 MPa.

3.3 Task for independent work

You must calculate:

- the bean diameter on the gas line (**Task 1)**;
- the bean diameter and the pressure at the outlet of the bean when there is a critical gas outflow (**Task 2)**.

Input data are presented in Table 3.1.

B – 1. .... 30 – the option numbers for **group "B"**;

B – 31. .... 60 – the option numbers for **group "G".**

3.4 Initial data

Legend:

- Q_P – volumetric flow rate of product, thousand m^3/day;
- p_1 – inlet pressure, MPa;
- p_2 – outlet pressure, MPa;
- T_1 – inlet gas temperature, K;
- M_G – molar mass of gas, kg/kmol;
- k – adiabatic index;
- μ_{bn} – dimensionless flow coefficient of the bean.

***R* = 8314.3 J/(kmol · K)** – universal gas constant (**for all variants**).

Table 3.1

B	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Q_P	240	250	260	280	320	240	250	260	280	280
p_1	8.50	8.40	8.50	8.30	8.40	8.60	8.70	8.40	8.50	8.70
p_2	5.3	5.8	6.5	7.0	6.4	6.2	5.3	5.8	6.5	7.0
T_1	280	290	285	295	300	280	290	285	295	300
M_G	30.1	30.3	30.5	30.1	30.3	30.5	30.1	30.3	30.5	30.1
k	1.28	1.26	1.29	1.30	1.27	1.28	1.29	1.30	1.27	1.28
μ_{bn}	0.95	0.96	0.97	0.98	0.95	0.96	0.97	0.98	0.95	0.96

B	***11***	***12***	***13***	***14***	***15***	***16***	***17***	***18***	***19***	***20***
Q_P	280	320	310	310	290	290	300	310	260	240
p_1	8.60	8.70	8.40	8.50	8.70	8.50	8.40	8.50	8.30	8.40
p_2	6.5	7.0	6.4	6.2	5.3	6.4	6.2	6.4	6.2	5.3
T_1	285	295	300	280	290	285	295	300	280	290
M_G	30.1	30.3	30.5	30.1	30.3	30.5	30.1	30.3	30.5	30.1
k	1.27	1.26	1.29	1.30	1.27	1.28	1.29	1.30	1.27	1.28
μ_{bn}	0.95	0.96	0.95	0.96	0.97	0.98	0.95	0.96	0.97	0.98
B	***21***	***22***	***23***	***24***	***25***	***26***	***27***	***28***	***29***	***30***
Q_P	300	290	310	270	290	290	280	270	290	280
p_1	8.50	8.40	8.50	8.30	8.40	8.60	8.70	8.40	8.50	8.70
p_2	6.4	6.2	5.3	6.5	7.0	6.4	6.2	5.3	6.4	6.2
T_1	285	295	285	295	300	280	290	285	295	300
M_G	30.1	30.3	30.5	30.1	30.3	30.5	30.1	30.3	30.5	30.1
k	1.28	1.26	1.29	1.30	1.27	1.28	1.29	1.30	1.27	1.28
μ_{bn}	0.95	0.96	0.97	0.98	0.98	0.95	0.96	0.97	0.98	0.95
B	***31***	***32***	***33***	***34***	***35***	***36***	***37***	***38***	***39***	***40***
Q_P	275	270	200	290	230	280	310	220	300	310
p_1	8.60	8.50	8.30	8.40	8.50	8.60	8.50	8.30	8.40	8.50
p_2	6.5	7.0	6.4	6.2	5.3	6.5	7.0	6.5	7.0	6.4
T_1	285	295	300	280	285	295	300	280	290	285
M_G	30.3	30.1	30.3	30.5	30.1	30.3	30.5	30.1	30.3	30.5
k	1.26	1.26	1.29	1.30	1.27	1.28	1.29	1.30	1.27	1.28
μ_{bn}	0.75	0.76	0.77	0.78	0.75	0.76	0.77	0.78	0.75	0.76
B	***41***	***42***	***43***	***44***	***45***	***46***	***47***	***48***	***49***	***50***
Q_P	300	290	220	220	300	210	260	240	200	290
p_1	8.50	8.40	8.50	8.30	8.40	8.50	8.30	8.40	8.60	8.70
p_2	6.5	7.0	6.5	7.0	6.4	6.2	5.3	6.5	7.0	6.4
T_1	285	295	300	280	290	290	285	295	300	280
M_G	30.3	30.5	30.1	30.3	30.5	30.1	30.3	30.5	30.1	30.3
k	1.27	1.26	1.29	1.30	1.27	1.28	1.29	1.30	1.27	1.28
μ_{bn}	0.75	0.76	0.77	0.78	0.75	0.76	0.77	0.78	0.75	0.76
B	***51***	***52***	***53***	***54***	***55***	***56***	***57***	***58***	***59***	***60***
Q_P	210	270	290	290	280	270	240	250	260	280
p_1	8.50	8.30	8.40	8.60	8.70	8.50	8.40	8.50	8.30	8.40
p_2	6.5	7.0	6.4	6.2	5.3	6.5	7.0	6.4	6.2	5.3
T_1	285	295	300	280	285	295	300	280	290	285
M_G	30.1	30.3	30.5	30.1	30.3	30.5	30.1	30.3	30.5	30.1
k	1.28	1.26	1.29	1.30	1.27	1.28	1.29	1.30	1.27	1.28
μ_{bn}	0.75	0.76	0.77	0.78	0.75	0.76	0.77	0.78	0.75	0.76

Practical work 4-Pr
Mechanical calculation of the maximum allowable depth of lowering the tubing column in the flowing well

3.1 Theoretical part

The limit depth of tubing lowering at the flowing well defined of strength condition, depending on the diameter and the group of the material pipes strength (steel mark D, E, K, L, M, P). As usual this limit depth is 1780-5500 m.

Maximum allowable depth of lowering monospaced column of pipes in the flowing well is determined by calculating of the action of its own weight, depending on the type of pipes, namely, m:

- for **full-strength tubes** (with thickened ends):

$$L_{Al1} = \frac{G_{\max}}{k_{saf} \cdot q_{tub} \cdot g} \tag{4.1}$$

- for **smooth tubes** (not full-strength):

$$L_{Al2} = \frac{G_{muv}}{k_{saf} \cdot q_{tub} \cdot g} \tag{4.2}$$

Where ***G***G_{max}, G_{muv} – respectively tensile load at which the tensions in the body of full-strength pipe reaches equal to the yield stress and ultimate joint strength of threaded connection of not full-strength (smooth) pipe, N (reference data – see Table 4.1);

k_{saf} – safety factor (usually taken equal to 1.5);

q_{tub} – weight of 1 meter of tubing pipe (including couplings or thickened ends), kg/m (reference data– see Table 4.2);

g – the acceleration of gravity, m/s^2.

If the packer used, starting valves or other devices, you should take into account and their weight in the calculation of the maximum allowable depth of lowering pipes.

4.2 A typical tasks

Task 1.

Perform mechanical calculation of tubing needed for the operation of the flowing (fountain) well.

Is known: There are obtained the following data:

– length of tubing pipes L = 1520 m;
– the tubing nominal diameter d = 0.060 m;
– pipe wall thickness s=5 mm (tubing internal diameter d_{in} = 0.0503 m);
– the length of one pipe l = 10 m;
– type of tubing pipes - smooth (not full-strength) tubes.

Solution. We calculate:

- the required number of pipes (number of pipes n_{pip} must be **an integer** with rounding toward higher value):

$$n_{pip} = \frac{L}{l} = \frac{1520}{10} = 152;$$

- required number of couplings:

$$n_{tj} = n_{pip} + 1 = 152 + 1 = 153;$$

- select of tables weight one meter pipe q_{pip} = 6.8 kg/m and weight of one clutch m_{tj} = 1.3 kg;

- weight of the tubing:

$$P_{tub} = \left(q_{pip} \cdot l \cdot n_{pip} + m_{tj} \cdot n_{tj}\right) \cdot g =$$

$$=(6.8 \cdot 10 \cdot 152 + 1.3 \cdot 153) \cdot 9.81 = 103.35 \cdot 10^3 \text{ N}.$$

For the given type of pipes (smooth tubes) should be selected group of the pipes material strength based on the material safety factor k_{saf} = 1.5. For smooth tubes the maximum loading is determined:

$$G'_{muv} = k_{saf} \cdot P_{tub} = 1.5 \cdot 103.35 \cdot 10^3 = 155.02 \cdot 10^3 \text{ N}.$$

Choose tubing from steel strength group D (Table 4.1), which ultimate joint strength of threaded connection G_{muv} = 204 kN, that is $G'_{muv} < G_{muv}$. So finally is selected 60x5D pipe GOST 633-80.

Answer: **smooth pipes GOST 633-80 60x5D**.

Task 2. Calculate the maximum allowable depth of lowering for monospaced column of selected diameter pipes.

Solution. We calculate q_{tub} – weight of 1 meter of smooth tubing pipe (including couplings):

$$q_{tub} = \frac{P_{tub}}{L \cdot g} = \frac{103{,}35 \cdot 10^3}{1520 \cdot 9{,}81} = 6{,}93\ kg/m$$

Maximum allowable depth of tubing pipe (4.2):

$$L_{Al2} = \frac{204 \cdot 10^3}{1{,}5 \cdot 6{,}93 \cdot 9{,}81} = 2000{,}5\ m$$

Answer: L = 2000,5 m.

Note. For **full-strength tubes** should be used tensile load G_{max} and equation (4.1).

4.3 Task for independent work

You must calculate:

- perform mechanical calculation of tubing (to select number and strength group of pipes) - **Task 1**;
- maximum allowable depth of tubing pipe - **Task 2**.

Input data are presented in Table 4.3.

B – 1. .... 30 - the option numbers for **group "B"**;

B – 31. .... 60 - the option numbers for **group "G".**

Table 4.1 – Allowable loads (tensile load G_{max} and ultimate joint strength G_{muv}) for various tubing

Tubing options	Strength group	Nominal diameter, mm					
		48	60	73	89	102	114
G_{max}, kN	D	208	324	435	627	724	880
	K	273	426	573	825	953	1158
	E	307	479	644	928	1071	1302
	L	364	568	763	1099	1269	1542
	M	422	658	884	1274	1471	1787
	P	518	807	1084	1563	1805	2193
G_{muv}, kN	D	117	204	289	437	450	556
	K	154	268	308	575	592	732
	E	173	302	427	646	665	832
	L	205	358	506	766	788	975
	M	238	415	587	887	913	1129
	P	292	508	720	1089	1121	1386
Cross-sectional area of the pipe body, cm^2	-	5.57	8.68	11.66	16.81	19.41	23.58
Cross-sectional area of flow channel cm^2	-	12.75	19.86	30.18	45.22	61.62	78.97

Table 4.2 – Geometric dimensions and weight of pipes (GOST 633-80)

Nominal diameter, mm	The outer diameter, mm	Wall thickness, ***s*** mm	The inner diameter, mm	The outer diameter of the coupling, mm	Weight, kg	
					1 m of pipe	Coupling
Smooth (not full-strength) tubes						
42	42.2	3.5	35.2	52.2	3.3	0.6
48	48.3	4	40.3	55.9	4.4	0.5
60	60.3	5	50.3	73.0	6.8	1.3
73	73	5.5	62.0	88.9	9.2	2.4
73	73	7	59.0	88.9	11.4	2.4
89	88.9	6.5	75.9	108	13.2	3.6
102	101.6	6.5	88.6	120.6	15.2	4.5
114	114.3	7	100.3	132.1	18.5	5.1
Full-strength tubes (with thickened ends)						
42	42.2	3.5	35.2	52.2	3.5	0.7
48	48.3	4	40.3	55.9	4.8	0.8
60	60.3	5	50.3	73.0	7.5	1.5
73	73	5.5	62.0	88.9	10.1	2.8
73	73	7	59.0	88.9	13.3	2.8
89	88.9	6.5	75.9	108	14.5	4.2
89	88.9	8	72.9	114.3	17.3	4.2
102	101.6	6.5	88.6	120.6	16.6	5.0
114	114.3	7	100.3	132.1	20.1	6.3

4.4 Initial data

Legend:

- ***L*** – length of tubing pipes, m;
- ***d*** – the conditional diameter of tubing, mm;
- ***s*** – pipe wall thickness, mm, – **see Table 4.2**;
- ***TT*** – tube type: **S - smooth tubes, F - full-strength tubes**
- ***l*** – the length of one pipe, m;

Table 4.3

B	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
L	1300	1450	1600	1800	1750	2000	1900	1700	1400	1650
d	48	60	73	89	102	114	48	60	73	89
TT	S	F	S	F	S	F	S	F	S	F
l	7	7.5	8	8.5	9	9.5	10	11	11.5	12
B	***11***	***12***	***13***	***14***	***15***	***16***	***17***	***18***	***19***	***20***
L	1300	1450	1600	1800	1750	2000	1900	1700	1400	1650
d	102	114	48	60	73	89	102	114	48	60
TT	S	F	S	F	S	F	S	F	S	F
l	9.5	10	11	11.5	12	7	7.5	8	8.5	9
B	***21***	***22***	***23***	***24***	***25***	***26***	***27***	***28***	***29***	***30***
L	1300	1450	1600	1800	1750	2000	1900	1700	1400	1650
d	73	89	102	114	48	60	73	89	73	89
TT	S	F	S	F	S	F	S	F	S	F
l	11	11.5	12	9.5	10	11	11.5	12	8.5	9
B	***31***	***32***	***33***	***34***	***35***	***36***	***37***	***38***	***39***	***40***
L	1300	1450	1600	1800	1750	2000	1900	1700	1400	1650
d	48	60	73	89	102	114	48	60	73	89
TT	S	F	S	F	S	F	S	F	S	F
l	11	11.5	12	9.5	10	11	11.5	12	8.5	9
B	***41***	***42***	***43***	***44***	***45***	***46***	***47***	***48***	***49***	***50***
L	1300	1450	1600	1800	1750	2000	1900	1700	1400	1650
d	73	89	102	114	48	60	73	89	73	89
TT	S	F	S	F	S	F	S	F	S	F
l	9.5	10	11	11.5	12	7	7.5	8	8.5	9
B	***51***	***52***	***53***	***54***	***55***	***56***	***57***	***58***	***59***	***60***
L	1300	1450	1600	1800	1750	2000	1900	1700	1400	1650
d	102	114	48	60	73	89	102	114	48	60
TT	S	F	S	F	S	F	S	F	S	F
l	7	7.5	8	8.5	9	9.5	10	11	11.5	12

Practical work № 5-Pr
Calculation of starting pressure for single-row gas lift elevator

5.1 Theoretical part

The design scheme of the pipes cross-section for the central and ring system of a single-row lift is shown in Fig. 5.1.

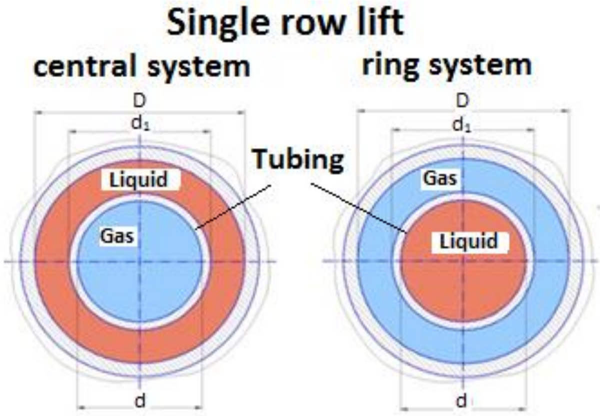

Figure 5.1 – The design scheme of the pipes cross-section for the central and ring system of a single-row lift.

The depth of immersion of lifting pipes shoe under **static fluid level** before starting well to work, m:

$$h = L - \frac{P_B}{\rho \cdot g} \tag{5.1}$$

where g - acceleration of gravity, m/s^2;

$\boldsymbol{P_B}$ - reservoir pressure, Pa;

$\boldsymbol{L}$ – tubing length, m;

$\boldsymbol{\rho}$ – liquid density, kg/m^3.

The general formula for determining the starting pressure:

$$P_{St} = h \cdot \rho \cdot g \cdot \left[1 + \alpha \cdot \frac{f_G}{f_L} \right] \tag{5.2}$$

where $\boldsymbol{f_G}$ – cross-sectional area of the space where the gas is injected;

$\boldsymbol{f_L}$ – cross-sectional area of the space where the liquid flows;

$\boldsymbol{\alpha}$ – coefficient which characterizes the fraction of absorbed liquid to reservoir of all displaced from the ring (for ring system) or tubing (for the central system) spaces. By specifying **α = 1**, we determine the greatest possible starting pressure.

Cross-sectional areas of pipe spaces, respectively: tubing F_T, and annular F_A (the presence of coupling is neglected), m:

$$F_T = \frac{\pi}{4} \cdot d^2; \quad F_A = \frac{\pi}{4} \cdot \left(D^2 - d_1^2 \right), \tag{5.3}$$

where $\boldsymbol{D}$ – internal diameter of the production string;

d₁ – the tubing external diameter;

d – the tubing internal diameter.

Starting pressure of gas injection for ring system (gas is pumped into the annulus), Pa:

$$P_{St}^{R} = h \cdot \rho \cdot g \cdot \left[1 + \alpha \cdot \frac{F_A}{F_T} \right] \tag{5.4}$$

Starting pressure of gas injection for central system (gas is pumped into the tubing), Pa:

$$P_{St}^{C} = h \cdot \rho \cdot g \cdot \left[1 + \alpha \cdot \frac{F_T}{F_A} \right] \tag{5.5}$$

5.2. A typical tasks

Calculate the starting pressure for a single-row gas-lift elevator of the ring and central systems.

Is known:

- internal diameter of the production string $\boldsymbol{D}$ = 0.125 m;
- tubing nominal diameter $\boldsymbol{d_N}$ **=** 60 mm;
- tubing length $\boldsymbol{L}$ = 2000 m;
- coefficient of absorbed liquid to reservoir $\boldsymbol{\alpha}$ = 1;
- liquid density (water-oil mixture), $\boldsymbol{\rho}$ = 985 kg/m^3;
- reservoir pressure $\boldsymbol{P_B}$ = 18 MPa.

Solution.

The depth of immersion of lifting pipes shoe under **static fluid level** before starting well to work:

$$h = L - \frac{P_B}{\rho \cdot g} = 2000 - \frac{18 \cdot 10^6}{985 \cdot 9.81} = 137.2m$$

The tubing dimensions at known nominal diameter $\boldsymbol{d_N}$ = 60 mm are determined from Table 4.2 Geometric dimensions and weight of pipes (**Practical work 4-Pr**):

- the tubing external diameter $\boldsymbol{d_1}$ = 0.0603 m;
- the tubing internal diameter $\boldsymbol{d}$ = 0.0503 m;

Cross-sectional areas of pipe spaces, tubing F_T, and annular F_A respectively:

$$F_T = \frac{\pi}{4} \cdot d^2 = \frac{\pi}{4} \cdot 0.0503^2 = 0{,}001987 m^2;;$$

$$F_A = \frac{\pi}{4} \cdot \left(D^2 - d_1^2\right) = \frac{\pi}{4} \cdot \left(0.125^2 - 0.0603^2\right) = 0.009416 m^2.$$

Starting pressure of gas injection for ring system:

$$P_{St}^{R}=h\cdot\rho\cdot g\cdot\left[1+1\cdot\frac{F_A}{F_T}\right]==137.2\cdot 985\cdot 9.81\cdot\left[1+1\cdot\frac{0.009416}{0.001987}\right]=7.61\cdot 10^{6}\,Pa$$

Starting pressure of gas injection for central system:

$$P_{St}^{C}=h\cdot\rho\cdot g\cdot\left[1+1\cdot\frac{F_T}{F_A}\right]==137.2\cdot 985\cdot 9.81\cdot\left[1+1\cdot\frac{0.001987}{0.009416}\right]=1.61\cdot 10^{6}\,Pa.$$

In the case the well switching at starting from the ring to the central system, the starting pressure is significantly reduced. The reduction factor is:

$$k=\frac{P_{St}^{R}}{P_{St}^{C}}=\frac{7.61\cdot 10^{6}}{1.61\cdot 10^{6}}=4.73$$

5.3. Task for independent work

You must calculate:

1. Starting pressure of gas injection for ring system gas-lift elevator.
2. Starting pressure of gas injection for central system gas-lift elevator.
3. Coefficient of starting pressure reduction when switching a well from ring to central system.

Input data are presented in Table 5.1.

B – 1. .... 30 - the option numbers for **group "B"**;

B – 31. .... 60 - the option numbers for **group "G".**

Table 5.1

Legend:

- ***D*** – internal diameter of the production string, mm;
- ***d_N*** – tubing nominal diameter, mm;
- ***L*** – tubing length, m;
- ***P_B*** **–** reservoir pressure, MPa;
- ***ρ_O*** – oil specific gravity, °API;
- ***ρ_W*** – water density, kg/m^3;
- ***n_W*** – water content ratio, %

α = 1 – coefficient of absorbed liquid to reservoir (**for all variants**).

B	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
D	178	205	109	134	145	154	165	194	115	130
d_N	102	114	48	60	73	89	102	114	48	60
L	1300	1450	1600	1800	1950	2100	2500	2700	1800	1850
P_B	12	13	14	15	16	17	20	21	15	17
ρ_O	10	20	15	30	40	25	35	30	20	10
ρ_W	1070	1025	1010	1015	1060	1035	1105	1015	1020	1030
n_W	20	10	40	15	25	30	10	20	30	5

B	***11***	***12***	***13***	***14***	***15***	***16***	***17***	***18***	***19***	***20***
D	141	156	178	201	111	130	147	146	143	150
d_N	73	89	102	114	48	60	73	89	73	89
L	2200	2300	1700	1800	1650	1900	2450	2400	1800	2150
P_B	12	18	14	15	16	17	20	21	15	17
ρ_O	25	35	30	20	10	10	20	15	30	40
ρ_W	1035	1045	1015	1020	1030	1040	1025	1015	1115	1060
n_W	20	10	15	25	30	35	15	10	35	20
B	***21***	***22***	***23***	***24***	***25***	***26***	***27***	***28***	***29***	***30***
D	178	205	109	134	145	154	165	194	115	130
d_N	102	114	48	60	73	89	102	114	48	60
L	1300	1450	1600	1800	2050	2100	2500	1700	1800	1650
P_B	12	13	14	15	16	17	20	11	15	12
ρ_O	13	22	18	30	44	27	32	30	24	14
ρ_W	1040	1025	1015	1115	1060	1035	1105	1015	1020	1030
n_W	20	10	40	15	25	30	10	20	30	5
B	***31***	***32***	***33***	***34***	***35***	***36***	***37***	***38***	***39***	***40***
D	141	156	178	201	111	130	147	146	143	150
d_N	73	89	102	114	48	60	73	89	73	89
L	2200	1900	1700	1900	1650	1900	1850	1600	1800	1950
P_B	10	13	14	15	13	17	12	11	15	14
ρ_O	24	31	36	24	16	12	28	12	31	41
ρ_W	1115	1060	1035	1105	1015	1040	1025	1015	1115	1060
n_W	30	10	20	30	5	35	15	10	35	20
B	***41***	***42***	***43***	***44***	***45***	***46***	***47***	***48***	***49***	***50***
D	176	205	109	134	145	154	167	194	115	130
d_N	102	114	48	60	73	89	102	114	48	60
L	1300	1450	1600	1800	1750	2100	1900	1700	1400	1650
P_B	12	13	14	15	16	17	20	21	15	17
ρ_O	15	20	15	34	45	25	35	30	20	13
ρ_W	1070	1025	1010	1015	1060	1035	1105	1015	1020	1030
n_W	35	15	10	35	20	30	15	20	30	5
B	***51***	***52***	***53***	***54***	***55***	***56***	***57***	***58***	***59***	***60***
D	141	156	178	201	111	130	147	146	143	150
d_N	73	89	102	114	48	60	73	89	73	89
L	2200	1900	1700	1400	1650	1300	1450	1600	1800	1750
P_B	10	13	14	15	16	17	20	21	15	17
ρ_O	25	33	30	20	15	18	20	15	30	40
ρ_W	1115	1060	1035	1045	1015	1040	1025	1015	1020	1030
n_W	30	10	25	30	15	35	15	10	35	20

Note: Oil density ρ_O = 141.5/(°API + 131.5) kg/l.

Practical work № 6-Pr
Thermal calculation of the pipeline

6.1 Theoretical part

To calculate the temperature at an arbitrary point x of gas pipeline (well flowline) is recommended a formula that takes into account influence of the Joule-Thomson effect:

$$T = T_g + \left(T_1 - T_g\right) \cdot e^{-ax} - Dj \frac{P_1^2 - P_2^2}{2 \cdot L \cdot a \cdot P_m} (1 - e^{-ax}) \tag{6.1}$$

where: $a = \dfrac{62.6 \cdot k_m \cdot D_{out}}{Q \cdot \Delta \cdot c_p \cdot 10^6}$;

Q - gas flow rate, million m^3/day (MCMD);

D$_{out}$ - the outer diameter of the pipeline, mm;

Δ - relative density (specific gravity) of the gas by air;

c$_P$ - specific heat (in approximate calculations $c_P \approx$ 0,6 kcal / (kg ·K));

x - distance from the beginning point to the point under consideration, km;

P$_1$ P$_2$ - pressure at the start and end of the gas pipeline, MPa;

P$_m$ - average gas pressure on the part of gas pipeline, MPa;

T$_1$ - the gas temperature at the start of the gas pipeline, K;

T$_g$ - ground temperature at a depth of laying the pipeline axis, K – Table 6.1;

L - total length of the gas pipeline, km;

k$_m$ - the coefficient of heat transfer from the gas to the ground, (in approximate calculations k_m = 1.5 kcal / (m^2 · h · K));

e - base of natural logarithms (e = 2.718);

Dj - Joule-Thomson effect (in approximate calculations for gas Dj≈3 K/MPa).

Table 6.1

Ground temperature *t$_g$*, °C per month for Kharkiv region												
Month	01	02	03	04	05	06	07	08	09	10	11	12
t$_g$, °C	2.7	1.9	1.6	4.0	9.6	13.2	15.8	16.7	15.2	11.6	7.7	4.6

The average pressure of gas pipeline P_m determined by the formula:

$$P_m = \frac{2}{3} \cdot (P_1 + \frac{P_1^2}{P_1 + P_2}) \tag{6.2}$$

The pressures at the intermediate points of the gas pipeline are calculated from equation

$$P_x = \sqrt{P_1^2 - (P_1^2 - P_2^2) \cdot \frac{x}{L}}, \tag{6.3}$$

where:

x - distance from the beginning point to the point under consideration, km;

L – total length of the gas pipeline, km;

At the points of the gas pipeline, for which are calculated the gas temperature and pressure, using graphics Figure 6.1 can be determined conditions of hydrate formation.

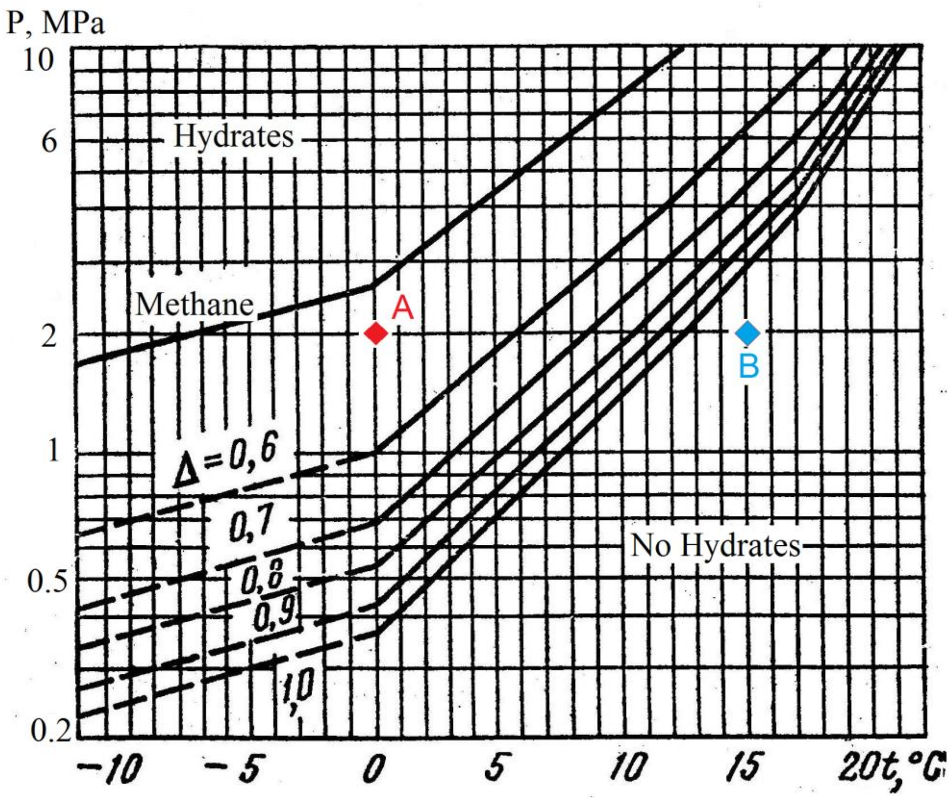

Figure 6.1 – Hydrate-forming conditions for natural gases with various relative densities. For gas with specific gravity Δ=0.6: Point A– hydrate-forming condition; Point B– no hydrate-forming condition

6.2 A typical tasks

To define temperature in the end points and temperature and pressure at several intermediate points (4 points) along the pipeline length;

Is known:

- D_{out} =700 mm - the outer diameter of the pipeline;
- L =12.5 km - length of the gas pipeline;
- Q =15 million m^3/day - gas flow rate;
- Δ = 0.7- relative density of the gas by air;
- t_1 =5 °C - the gas temperature at the start of the gas pipeline;
- P_1 = 5 MPa, P_2 = 4.5 MPa - pressures at the start and end of the pipeline;
- M =8 - month of the year.

Solution.

First, is necessary to calculate gas temperature in the end point and in 4 intermediate points along the pipeline length with help equation (6.1).

Next is necessary to calculate gas pressure in 4 intermediate points along the pipeline length with help equation (6.3).

The results of calculations need to make in the columns of the Table 6.2.

Table 6.2

Point	L, km	T °C	P,MPa	Conditions of hydrate formation
1	0	5	5	Yes
2	2,5	5,597078	4,90408	Yes
3	5	6,178783	4,806246	Yes
4	7,5	6,745511	4,706379	Yes
5	10	7,297648	4,604346	Yes
6	12,5	7,83557	4,5	Yes

According to the calculation of the gas temperature in the start and end points of the gas pipeline as well as in 4 intermediate points should be constructed curves of temperature and pressure change on the pipeline route Figure 6.2.

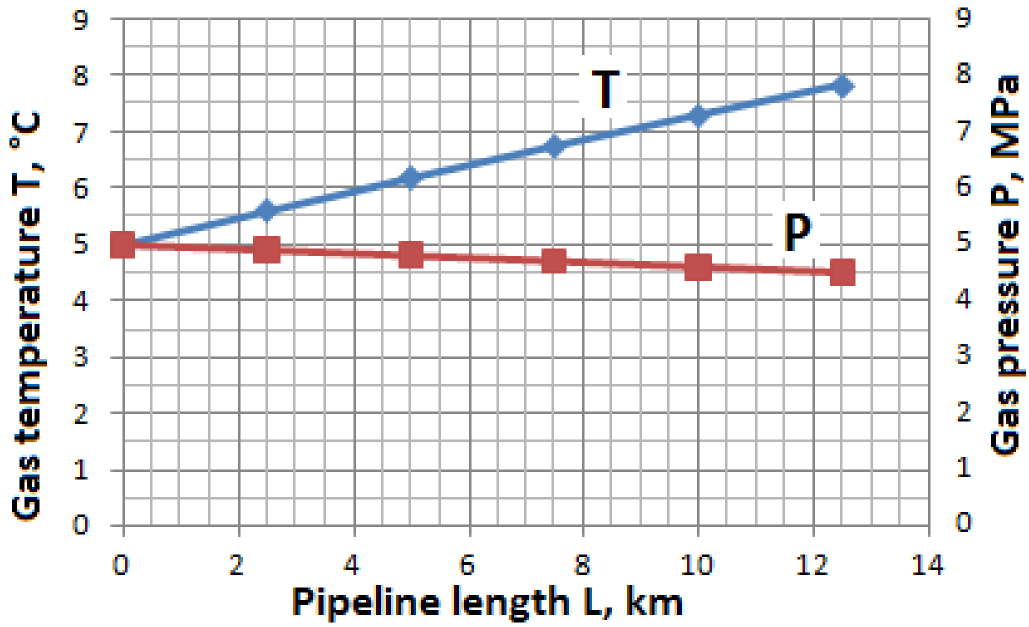

Figure 6.2 – Curves of temperature and pressure change on the pipeline route

For the gas pipeline points which are calculated the gas temperature and pressure, using graphics Figure 6.3 can be determined conditions of hydrate formation (“Yes” or “No”) and written to the last column of the Table 6.2.

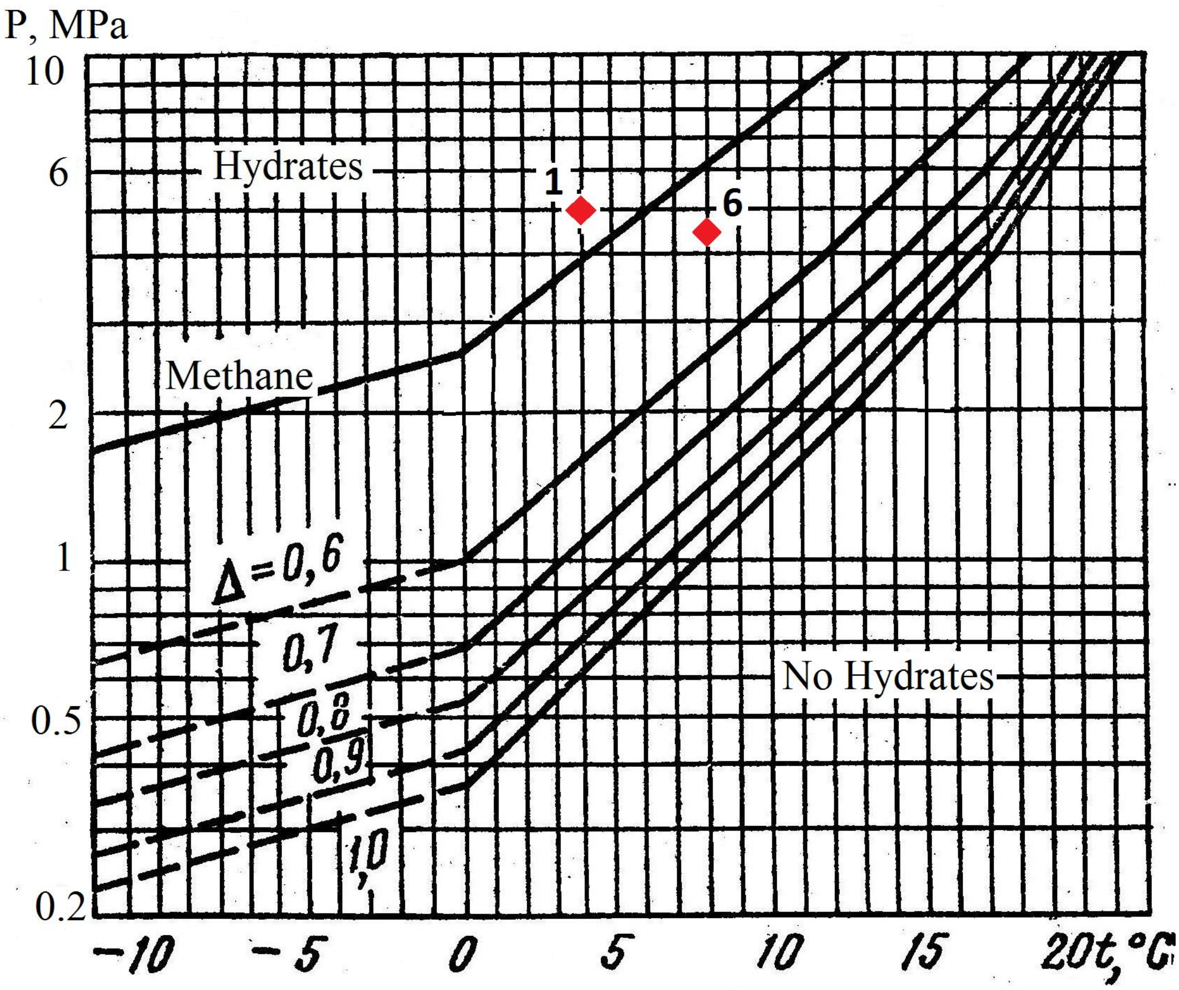

Figure 6.3 – Hydrate-forming conditions. Point 1 corresponds to the beginning of the pipeline, the point 6 corresponds to the end of the pipeline. For gas with specific gravity Δ=0.7 both points are in the zone the hydrate formation.

6.3. Tasks for independent work

You have:

- to define temperature in the end points and temperature and pressure at several intermediate points (4 points) along the pipeline length;
- to build curves parameter changes (temperature and pressure) along the pipeline length;
- to check the conditions of hydrate formation in reference points;
- to complete the table of calculation results

Input data are presented in Table 6.3.

N – 1, ..., 30 - the variant numbers for the **group "B"**,

N – 31, ..., 60 - the variant numbers for the **group "G".**

5.4 Initial data

Legend:

- ***N – 1, ..., 60*** - the variant number;
- D_{out} - the outer diameter of the pipeline, mm;
- ***L*** - length of the gas pipeline, km;
- ***Q*** - gas flow rate, million m^3/day;
- ***Δ*** - relative density of the gas by air;
- t_1 - the gas temperature at the start of the gas pipeline, °C;
- P_1 P_2 - pressures at the start and end of the pipeline, MPa;
- ***M*** – month of the year.

Table 5.3

N	D_{out}	L	Q	Δ	t1	P_1	P_2	M
1	100	5	0.1	0.6	15	4	3.5	1
2	150	5	0.5	0.6	15	4	3.5	2
3	200	5	1	0.6	15	4	3.5	3
4	300	5	2	0.6	15	4	3.5	4
5	500	5	10	0.6	15	4	3.5	5
6	700	5	20	0.6	15	4	3.5	6
7	100	7.5	0.1	0.6	10	4	3.2	7
8	150	7.5	0.5	0.6	10	4	3.2	8
9	200	7.5	1	0.6	10	4	3.2	9
10	300	7.5	2	0.6	10	4	3.2	10
11	500	7.5	10	0.6	10	4	3.2	11
12	700	7.5	20	0.6	10	4	3.2	12
13	100	10	0.12	0.6	20	4	3	1
14	150	10	0.4	0.6	20	4	3	2
15	200	10	0.8	0.6	20	4	3	3
16	300	10	2.5	0.6	20	4	3	4
17	500	10	8	0.6	20	4	3	5
18	700	10	16	0.6	20	4	3	6
19	100	7.5	0.1	0.7	15	5	4	7
20	150	7.5	0.5	0.7	15	5	4	8
21	200	7.5	1	0.7	15	5	4	9
22	300	7.5	2	0.7	15	5	4	10
23	500	7.5	10	0.7	15	5	4	11
24	700	7.5	20	0.7	15	5	4	12
25	100	10	0.12	0.7	10	5	4.2	1
26	150	10	0.4	0.7	10	5	4.2	2
27	200	10	0.8	0.7	10	5	4.2	3
28	300	10	2.5	0.7	10	5	4.2	4
29	500	10	8	0.7	10	5	4.2	5

30	700	10	16	0.7	10	5	4.2	6
31	100	15	0.1	0.8	7	6	5.3	1
32	150	15	0.5	0.8	6	6	5.3	2
33	200	15	1	0.8	5	6	5.3	3
34	300	15	2	0.8	4	6	5.3	4
35	500	15	10	0.8	3	6	5.3	5
36	700	15	20	0.8	7	6	5.3	6
37	100	20	0.12	0.8	6	5.5	4.5	7
38	150	20	0.6	0.8	5	5.5	4.5	8
39	200	20	1.2	0.8	4	5.5	4.5	9
40	300	20	24	0.8	3	5.5	4.5	10
41	500	20	12	0.8	7	5.5	4.5	11
42	700	20	25	0.8	6	5.5	4.5	12
43	100	15	0.1	0.8	5	4	3.5	1
44	150	15	0.5	0.8	4	4	3.5	2
45	200	15	1	0.6	3	4	3.5	3
46	300	15	2	0.6	7	4	3.5	4
47	500	15	10	0.6	6	4	3.5	5
48	700	15	20	0.6	5	4	3.5	6
49	100	20	0.12	0.6	4	4.5	3.7	7
51	200	20	0.8	0.7	0	4.5	3.7	9
52	300	20	2.5	0.7	15	4.5	3.7	10
53	500	20	8	0.7	10	4.5	3.7	11
54	700	20	16	0.7	15	4.5	3.7	12
55	100	20	0.12	0.7	10	4.8	4	7
56	150	20	0.4	0.7	8	4.8	4	8
57	200	20	0.8	0.7	2	4.8	4	9
58	300	20	2.5	0.7	1	4.8	4	10
59	500	20	8	0.7	0	4.8	4	11
60	700	20	16	0.7	5	4.8	4	12

Appendix 1

National Technical University "Kharkov Polytechnic Institute"

Department "Oil, Gas and Condensate Extraction"

Subject:

OIL AND GAS PRODUCTION TECHNOLOGY

<u>Practical work № ___</u>

____

(title of practical work)

____

(option number of the practical work initial data)

Performed by the student of the group _______

____

Checked by _____________________________

____

Kharkov – 201__